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Patentanmeldung Nr. Patent application No. Demande de brevet n°

99310407.4

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**Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation**

Anmeldung Nr.:
Application no.: 99310407.4
Demande n°:

Anmeldetag:
Date of filing: 22/12/99
Date de dépôt:

Anmelder:
Applicant(s):
Demandeur(s):
ASM LITHOGRAPHY B.V.
5503 LA Veldhoven
NETHERLANDS

Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention:

Position detection system for use in lithographic apparatus

In Anspruch genommene Priorität(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

Staat:
State:
Pays:

Tag:
Date:
Date:

Aktenzeichen:
File no.
Numéro de dépôt:

Internationale Patentklassifikation:
International Patent classification:
Classification internationale des brevets:

/

Am Anmeldetag benannte Vertragsstaaten:
Contracting states designated at date of filing: AT/BE/CH/CY/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE
Etats contractants désignés lors du dépôt:

Bemerkungen:
Remarks:
Remarques:

P-0166.000-EP

Position Detection System for use in Lithographic Apparatus

The present invention relates to a position detection system, such as may be used to determine a reference position of a moveable object. More particularly, the invention relates to the use of the position detection apparatus in lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a first object table provided with a mask holder for holding a mask;
- a second object table provided with a substrate holder for holding a substrate;
- 10 a projection system for imaging irradiated portions of the mask onto target portions of the substrate; and
- a reference frame.

15 For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The radiation system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam of radiation, and such elements may also be referred to below, collectively or singularly, as a "lens". In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively. Further, the lithographic apparatus may be of a type having two or more mask tables and/or two or more substrate tables. In such "multiple table" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Twin table lithographic apparatus are described in International Patent Applications WO 98/28665 and WO 98/40791, for example.

30 Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target area (die) on a substrate (silicon wafer) which has been coated with a layer

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of photosensitive material (resist). In general, a single wafer will contain a whole network of adjacent dies which are successively irradiated via the reticle, one at a time. In one type of lithographic projection apparatus, each die is irradiated by exposing the entire reticle pattern onto the die in one go; such an apparatus is commonly referred to
5 as a wafer stepper. In an alternative apparatus — which is commonly referred to as a step-and-scan apparatus — each die is irradiated by progressively scanning the reticle pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the wafer table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M
10 (generally < 1), the speed at which the wafer table is scanned will be a factor M times that at which the reticle table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205.

In a lithographic apparatus, the size of features that can be imaged onto the wafer
15 is limited by the wavelength of the projection radiation. To produce integrated circuits with a higher density of devices and hence higher operating speeds, it is desirable to be able to image smaller features. Whilst most current lithographic projection apparatus employ ultraviolet light generated by mercury lamps or excimer lasers, it has been proposed to use higher frequency (energy) radiation, e.g. EUV or X-rays, or particle
20 beams, e.g. electrons or ions, as the illumination radiation in lithographic apparatus.

Whatever the type of lithographic apparatus it is necessary to determine accurately the position of moveable parts, such as the object tables, at any given time. Conventionally this is done using incremental sensors, such as encoders or interferometers, that is sensors which measure change in position rather than position
25 absolutely. It is therefore necessary to provide an additional zero reference sensor, which detects when the moveable object is at the reference or zero position, to provide a basis from which the incremental position measurements can be used to calculate an absolute position. Such zero reference systems can often offer a repeatability of $1\ \mu\text{m}$ or better.

30 In a substrate or mask positioning system it is often desirable to be able to position the mask or substrate in all 6 degrees of freedom (DOF). Six zero reference systems and six incremental positioning systems are therefore coupled together in a

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kinematic chain which can result in cumulative repeatability errors which are unacceptably high. Furthermore, the zero reference of the holder is often referenced to a vibration-isolated reference frame, onto which only the most critical metrology components are mounted. Zero references of encoder systems for coarse positioning do not fit into this category and so are mounted on separate structures, the position of which remains undefined at micrometer level relative to the isolated reference frame.

An object of the present invention is to provide a referencing system which allows repeatable referencing, preferably to sub-micrometer accuracy, of a moveable object relative to a reference frame. Ideally the system should provide the ability to reference the moveable object in six degrees of freedom simultaneously.

According to the present invention there is provided a lithographic projection apparatus comprising:

- 15 a radiation system for supplying a projection beam of radiation;
- a first object table provided with a mask holder for holding a mask;
- a second object table provided with a substrate holder for holding a substrate;
- a projection system for imaging irradiated portions of the mask onto target portions of the substrate; and
- 20 a reference frame; characterized by:
 - a position detection device comprising:
 - a radiation source mounted on said reference frame;
 - a two-dimensional radiation detector mounted in a fixed position adjacent said radiation source; and
- 25 a mirroring device mounted on one of said object tables that is moveable relative to said reference frame so as to reflect radiation emitted by said radiation source toward said radiation detector.

The above described position detection device can measure the position of the object table in two degrees of freedom; to detect its position in six degrees of freedom, three such position detection devices having mutually different (i.e. not parallel), preferably substantially orthogonal, orientations may be provided in the lithographic projection apparatus.

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The radiation source is preferably a source of collimated radiation and may comprise a monochromatic light source such as an LED or laser diode mounted on the sensor housing or away from the reference frame and with an optical fibre to bring light emitted by said light source to beam directing optics mounted on said reference frame.

- 5 This latter arrangement has the advantage of high pointing stability of the collimated light beam as well as removing a potential heat source from the reference frame.

- The two-dimensional position detector may be a two-dimensional PSD (position sensing detector), a CCD camera, a four quadrant photo-detector or any suitable two-dimensional detector array which can provide an output signal in each of two
10 orthogonal directions as a function of the position of the reflected light beam on the detector (array).

According to a further aspect of the invention there is provided a method of manufacturing a device using a lithographic projection apparatus comprising:

- 15 a radiation system for supplying a projection beam of radiation;
a first object table provided with a mask holder for holding a mask;
a second object table provided with a substrate holder for holding a substrate;
a reference frame; and
a projection system for imaging irradiated portions of the mask onto target
20 portions of the substrate; the method comprising the steps of:
providing a mask bearing a pattern to said first object table;
providing a substrate provided with a radiation-sensitive layer to said second object table;
irradiating portions of the mask and imaging said irradiated portions of the mask
25 onto said target portions of said substrate; characterized in that:
prior to or during said steps of irradiating and imaging, one of said object tables that is moveable relative to said reference frame is determined to be in a reference position by the steps of emitting radiation from a radiation source mounted on said reference frame toward a mirroring device mounted on said one object table, reflecting
30 the radiation by said mirroring device and detecting the reflected radiation in a two-dimensional radiation detector mounted in a fixed position adjacent said radiation source.

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In a manufacturing process using a lithographic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft
5 bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallisation, oxidation, chemo-mechanical
10 polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins,
15 etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

20 Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic
25 heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target area", respectively.

In the present document, the terms "radiation" and "beam" are used to
30 encompass all types of electromagnetic radiation or particle flux, including, but not limited to, ultraviolet (UV) radiation (e.g. at a wavelength of 365nm, 248 nm, 193 nm, 157nm or 126nm), extreme ultraviolet (EUV) radiation, X-rays, electrons and ions.

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The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic projection apparatus according to a first
5 embodiment of the invention;

Figure 2 is a plan view of a position detecting system according to the invention;
and

Figure 3 is a partial cross-sectional view of the position detection system of
Figure 2.

10 In the drawings, like reference numerals indicate like parts.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus according to
15 the invention. The apparatus comprises:

- a radiation system LA, Ex, IN, CO for supplying a projection beam PB of radiation (e.g. UV or EUV radiation);
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately
20 positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (e.g. a refractive or catadioptric system, a mirror
25 group or an array of field deflectors) for imaging an irradiated portion of the mask MA onto a target portion C (die) of the substrate W.

As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example.

The radiation system comprises a source LA (e.g. a Hg lamp, excimer laser, an
30 undulator provided around the path of an electron beam in a storage ring or synchrotron, or an electron or ion beam source) which produces a beam of radiation. This beam is passed along various optical components comprised in the illumination

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system, — e.g. beam shaping optics Ex, an integrator IN and a condenser CO — so that the resultant beam PB is substantially collimated and uniformly intense throughout its cross-section.

- The beam PB subsequently intercepts the mask MA which is held in a mask holder on a mask table MT. Having passed through the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target area C of the substrate W. With the aid of the interferometric displacement and measuring means IF, the substrate table WT can be moved accurately, e.g. so as to position different target areas C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library. In general, movement of the object tables MT, WT will be realized with the aid of a long stroke module (course positioning) and a short stroke module (fine positioning), which are not explicitly depicted in Figure 1. The depicted apparatus can be used in two different modes:
- 15 • In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single “flash”) onto a target area C. The substrate table WT is then shifted in the x and/or y directions so that a different target area C can be irradiated by the beam PB;
 - In scan mode, essentially the same scenario applies, except that a given target area C is not exposed in a single “flash”. Instead, the mask table MT is movable in a given direction (the so-called “scan direction”, e.g. the x direction) with a speed v , so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target area C can be exposed, without having to compromise on resolution.

Figure 2 shows in plan an embodiment of the present invention used in conjunction with the wafer table WT. It will be appreciated that the present invention can also be used with a mask (reticle) table. The wafer W and reference X & Y axes are shown in phantom. The Z axis is normal to the X and Y axes. The position detection

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system according to the invention comprises three similar position detection apparatus 10A, 10B, 10C. Each position detection apparatus comprises a radiation source 11 which emits an incident beam 12 of collimated radiation towards a retro-reflector 13, that is a reflector which reflects the incident light onto a return path that is parallel to
5 but displaced from the incident light path. The displacement of the return beam 14, in two dimensions, is a function of the relative position of the radiation source and the reflector in a plane normal to the incident beam 12. The retro-reflector 13 may, for example, be constructed from three mutually perpendicular plane reflectors meeting at a single corner. The reflectors may be formed by providing a mirror coating on three
10 external faces of a corner (notionally) cut from a transmissive cube. The return beam 14 impinges on a two-dimensional radiation detector 15.

The radiation source 11 and radiation detector 15 are mounted adjacent to one another and on the isolated reference or metrology frame MF of the lithographic apparatus in a highly stable manner. Conveniently, the radiation source 11 and
15 radiation detector 15 may be mounted to each other or to a single bracket 16, shown in Figure 3. The housing(s) and/or mounting bracket(s) of the position detector 15 and radiation source 11 are preferably made of a material with very low thermal coefficient of expansion, such as Zerodur (RTM) or Invar, for high thermal stability. The isolated reference or metrology frame MF may also be made of such a material. The retro-
20 reflector 13 is mounted on the wafer table WT at a convenient location, e.g. near one corner.

The two-dimensional position detector 15 may be a two-dimensional PSD, a CCD camera, a four quadrant photo-detector or any suitable two-dimensional detector array and is mounted with its sensing plane substantially perpendicular to the incident
25 and reflected beams 12, 14.

The positions of the position detection apparatus 10A, 10B, 10C and their orientations, i.e. angles α , β , γ , are selected to provide the highest possible balanced positional sensitivity in all 6 degrees of freedom. In a specific application of the invention the position and orientations will be determined by factors such as the shape
30 of the wafer table and reference frame as well as the differing sensitivities of the lithographic apparatus to positional, pitch, roll and yaw errors.

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Figure 3 is a partial cross-sectional view of one position detection apparatus 10. As can there be seen the radiation source 11 and radiation detector 15 are mounted via bracket 16 to the metrology frame MF at such a position that the incident and return beams 12, 14 are inclined at an angle δ to the X-Y plane, to which the wafer W is substantially parallel. Angle δ is preferably substantially 45° so that horizontal and vertical displacements of the reflector 13 relative to the incident light beam 12 of equal magnitude result in equal displacement of the return light beam 14 on the radiation detector 15.

As shown in Figure 3, the radiation source 11 is formed of a LED or laser diode 111 or a similar monochromatic light source for emitting light into a single mode optical fibre 112 which leads that light to collimating optics 113 mounted on the metrology frame MF. In this way the light source 111 can be placed away from the metrology frame MF and thermally isolated from it. The removal of the light source from the detector housing also leads to much higher pointing stability of the collimated beam with respect to the sensor/detector.

The three position detection apparatus of the invention, forming a position sensing system, provide six signals dependent on the position and orientation of the wafer table WT. The system can be used in two modes:

- as a zero-seeking system; the substrate holder is moved until all three detectors give their zero output in all 6 degrees of freedom;
- as a position measurement system; the sensor signals are transformed by an appropriate electronic or micro-processor based control systems (not shown) to six degree of freedom positioning information relative to the isolated reference frame as required by any servo or other control devices. This can be done by sampling the sensors simultaneously or in sequence.

Ideally, the positions of the radiation source/detector units on the metrology (reference) frame and the reflectors on the table are such that the table can be moved to a position where zero outputs are given for all six degrees of freedom simultaneously. (It should be noted though that the "zero" position need not be the position at which all detectors give their zero or mid range outputs; any repeatable and unique combination of output signals from the three 2-dimensional detectors can be defined as the zero position.) In other words, the capture zones of all the detection apparatus 10A, 10B,

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10C should overlap. However, it may not always be possible because of the requirements of other components of the device to arrange this. In that case, the table may be moved between the capture zones of each of apparatus 10A, 10B, 10C and position signals from the incremental detector indicating the movement of the table
5 between specific positions as indicated by the reference detection apparatus 10A, 10B, 10C used to determine the zero reference position.

It should also be noted that the referencing process may be either static, or dynamic. In a static process, the table is moved to the reference position(s) and held stationary whilst the necessary measurements are made. In a dynamic process, which
10 depends on the sampling frequency of the various sensors being high enough, the table may simply be moved through or near the reference position(s) and referencing of the system can be calculated from coincident measurements from the absolute and incremental reference systems. If the table does not actually pass through the reference position(s), or if samples of the measurement systems do not coincide with that passage,
15 the measurements taken may be extrapolated or interpolated as required.

The present invention has been illustrated when used to detect the position of the wafer (substrate) holder of a lithographic apparatus. It will readily be appreciated that the invention can also be used to detect the position of a mask (reticle) holder in a
20 lithographic apparatus or, indeed, any other moveable object.

A significant advantage of the position detection signal of the present invention is that there is no residual force between the metrology (reference) frame and the wafer table, as there is in the case of inductive, magnetic or capacitive sensors. This is important as the reference or metrology frame is isolated in 6 degrees of freedom with
25 extremely low Eigen-frequencies for maximum stability. Any disturbance forces, that might be transmitted to the frame by sensors that do involve a force coupling, would result in vibrations that would take a very long time to stabilize.

A second advantage derives from the use of collimated light. This means that the sensitivity of the sensor is substantially independent of working distance, allowing
30 greater flexibility in the layout of the reference frame, sensor modules and object table.

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Whilst we have described above a specific embodiment of the invention it will be appreciated that the invention may be practiced otherwise than described. In particular, the invention may be used to zero reference a metrology system for detecting the position of either a substrate (wafer) table or a mask (reticle) table in a lithographic apparatus. Further, in a lithographic apparatus with multiple (substrate or mask) tables and/or multiple working zones (e.g. exposure and measurement or characterization zones), multiple systems may be provided with the static parts (radiation source and detector) provided in or adjacent each working zone and reflectors provided on each table. The different sets of radiation source and detector may operate in conjunction with reflectors on any table that can be positioned within their areas of operation. The description is not intended to limit the invention.

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CLAIMS

1. A lithographic projection apparatus comprising:
 - a radiation system for supplying a projection beam of radiation;
 - 5 a first object table provided with a mask holder for holding a mask;
 - a second object table provided with a substrate holder for holding a substrate;
 - a projection system for imaging irradiated portions of the mask onto target portions of the substrate; and
 - a reference frame; characterized by:
 - 10 a position detection device comprising:
 - a radiation source mounted on said reference frame;
 - a two-dimensional radiation detector mounted in a fixed position adjacent said radiation source; and
 - a mirroring device mounted on one of said object tables that is moveable
 - 15 relative to said reference frame so as to reflect radiation emitted by said radiation source toward said radiation detector.
2. Apparatus according to claim 1 wherein said radiation source is a source of collimated radiation.
- 20 3. Apparatus according to claim 1 or 2 wherein said radiation source is a source of monochromatic radiation.
4. Apparatus according to claim 1, 2 or 3 wherein said mirroring device is a retro-
25 reflector.
5. Apparatus according to any one of the preceding claims wherein said radiation source comprises a light source mountable away from the reference frame, beam directing optics mountable on said reference frame and an optical fiber to couple said
30 light source to said beam directing optics.

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6. Apparatus according to any one of the preceding claims wherein said radiation source comprises a laser diode, or an LED as a light source.

7. Apparatus according to any one of the preceding claims wherein said two-
5 dimensional position detector is a two-dimensional PSD, or a CCD camera, or a four quadrant photo-detector.

8. Apparatus according to any one of the preceding claims wherein said retro-reflector comprises a trapezoid form of a material transparent to said radiation and
10 having three mutually perpendicular surfaces meeting at a corner, said three surfaces being provided with a reflective coating.

9. Apparatus according to any one of the preceding claims comprising three position detection devices as therein defined.

15

10. Apparatus according to any one of the preceding claims further comprising an incremental position sensing device for detecting the position of said moveable object table in a detection range wider than that of said position detection device and means for combining output signals from said incremental position sensing device and said
20 position detector to determine an absolute position of said object table in said detection range.

11. A method of manufacturing a device using a lithographic projection apparatus comprising:

25

a radiation system for supplying a projection beam of radiation;
a first object table provided with a mask holder for holding a mask;
a second object table provided with a substrate holder for holding a substrate;
a reference frame; and
a projection system for imaging irradiated portions of the mask onto target

30 portions of the substrate; the method comprising the steps of:

providing a mask bearing a pattern to said first object table;

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providing a substrate provided with a radiation-sensitive layer to said second object table;

irradiating portions of the mask and imaging said irradiated portions of the mask onto said target portions of said substrate; characterized in that:

- 5 prior to or during said steps of irradiating and imaging, one of said object tables that is moveable relative to said reference frame is determined to be in a reference position by the steps of emitting radiation from a radiation source mounted on said reference frame toward a mirroring device mounted on said one object table, reflecting the radiation by said mirroring device and detecting the reflected radiation in a two-
10 dimensional radiation detector mounted in a fixed position adjacent said radiation source.

12. A method according to claim 11, wherein said lithographic projection apparatus further comprises an incremental position sensing system for sensing the position of said
15 one object table, said method comprising the further step, after said one object table is determined to be in said reference position, of determining the absolute position of said one object table by measuring movements thereof relative to said reference position using said incremental position sensing system.

- 20 13. A device manufactured according to the method of claim 11 or 12.

14. A position detection apparatus comprising:
a radiation source mounted on said reference frame;
a two-dimensional radiation detector mounted in a fixed position adjacent said
25 radiation source; and
a mirroring device mounted on an object that is moveable relative to said reference frame so as to reflect radiation emitted by said radiation source toward said radiation detector.

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ABSTRACT

Position Detection System for use in Lithographic Apparatus

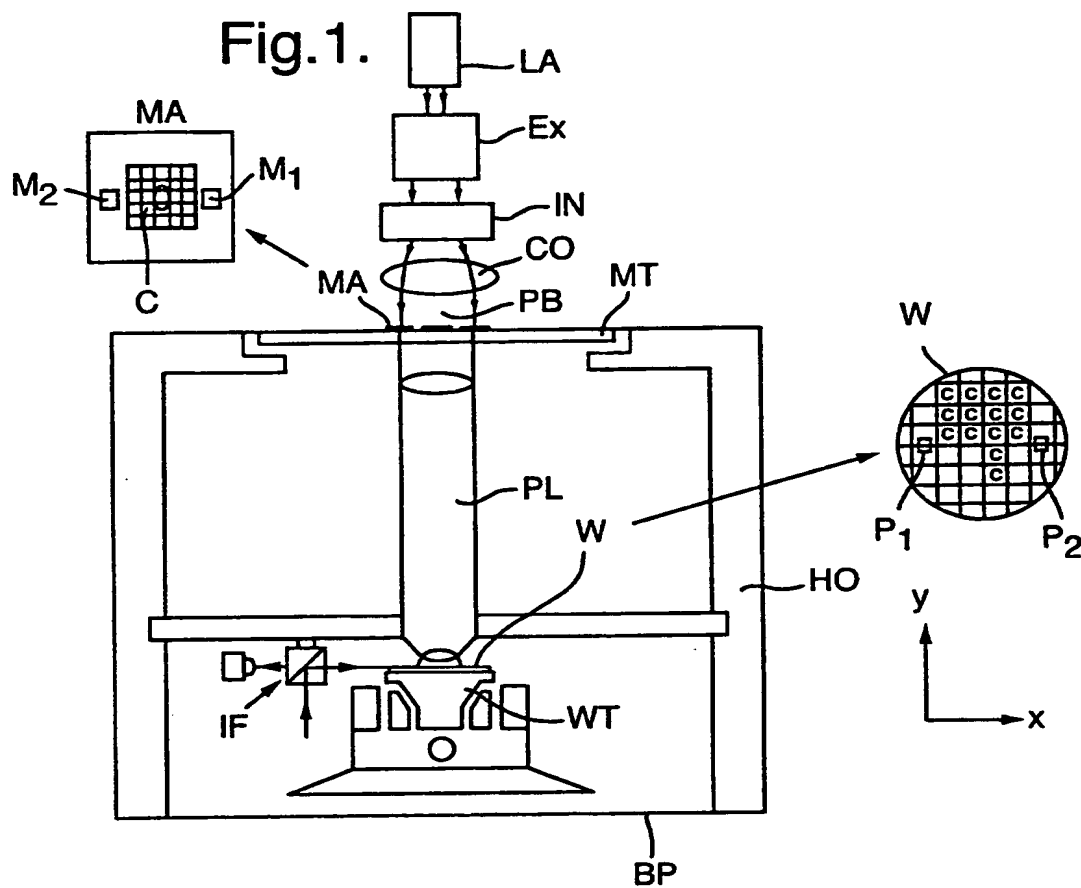
5 A position detection apparatus comprises a radiation source mounted on an isolated reference frame and a two-dimensional detector mounted adjacent said radiation source. The object whose position is to be detected has a retro-reflector mounted on it so as to reflect light emitted from the radiation source along a return path that is parallel to but displaced from the incident light path. The amount of displacement is dependent
10 on the position of the object and is measured by the two-dimensional detector. Three such apparatus can be combined in a system to measure the position of the object in all six degrees of freedom.

Fig. 2



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Fig. 2

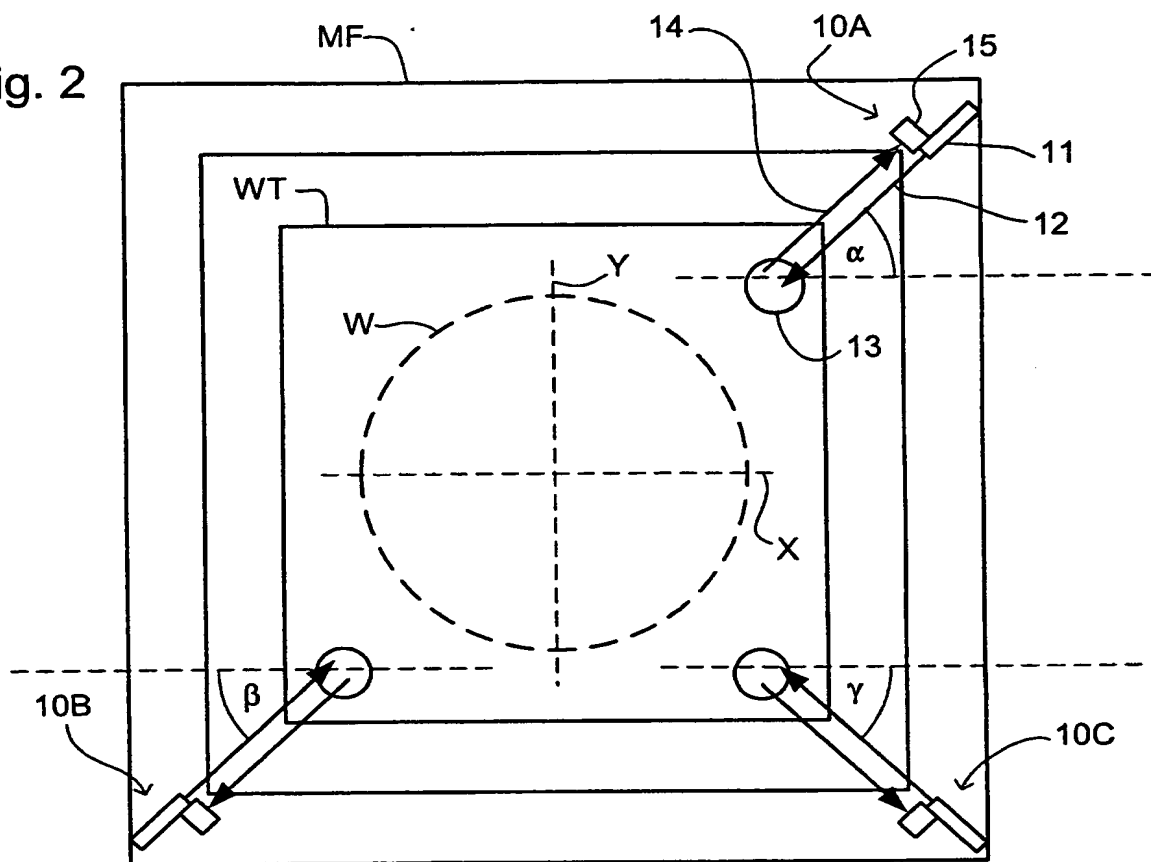


Fig. 3

